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On an Inversion of Ideas as to the Structure of the Universe

London: C. J. CLAY AND SONS,
CAMBRIDGE UNIVERSITY PRESS WAREHOUSE,
AVE MARIA LANE.
Glasgow: 50, WELLINGTON STREET.

Leipzig: F. A. BROCKHAUS.
New York: THE MACMILLAN COMPANY.
Bombay and Calcutta: MACMILLAN AND CO., LTD.

On an Inversion of Ideas as to the Structure of the Universe

(The Rede Lecture, June 10, 1902)

by

Osborne Reynolds

M.A., F.R.S., LL.D., Mem. Inst. C.E.
Professor of Engineering in the
Owens College, Manchester;
Honorary Fellow of Queens' College, Cambridge

CAMBRIDGE
at the University Press
1903

Cambridge:
PRINTED BY J. AND C. F. CLAY,
AT THE UNIVERSITY PRESS.

First Edition 1902.
Reprinted 1903.

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ON AN INVERSION OF IDEAS AS TO THE STRUCTURE OF THE UNIVERSE.

1. *Evidence afforded by the outward facts of nature.*

The general problem of the universe, as hitherto presented by the phenomena which Tyndall, in this house, called "the outward facts of nature," demands that matter, besides being continuous in time and occupying space to exclusion of other matter shall have such physical properties as admit:

(1) of conditions in space which allow of motions of matter, like those of the earth and planets round the sun, at velocities of upwards of 20 miles a second, with scarcely any diminution after thousands of years; *i.e.* they must admit of a perfect vacuum of matter, such as would be obtained by a perfect air-pump;

(2) they must also allow of the transmission of light, such as is being transmitted through these windows, to be reflected or absorbed by the opposite wall;

(3) of the gravitation of matter, as when I drop this ball;

(4) of the limited cohesion of matter, on which the strength of our structures depend. Thus I can break this stick of sealing-wax, and when I warm the ends and bring them together, when cold it is as strong as before;

(5) of the elasticity of matter, as shown by the continued vibration of this spring;

(6) of the limited friction of matter, as is shown by the weight resting on the inclined plane until the inclination reaches a certain angle, when it slides down at an accelerating rate;

(7) of the viscosity of matter, as is shown by putting oil on the inclined plane, when the weight slides down slowly and at a steady rate;

(8) of the electric and magnetic properties of matter, shown by the absence of any affinity of the stick of sealing-wax for the paper until it is rubbed by silk, when it at once picks up the paper;

(9) of the freedoms and mutual constraints

of the molecules of matter, shown by the uniform pressure of the air in this room;

(10) of the combination and dissociations of molecules, as shown respectively by any combustion and any electrolytic decompositions.

2. *Phenomena not hitherto explained.*

That the physical properties demanded for the mechanical explanation of the ten phenomena illustrated, as well as others, exist, is certain.

But it is equally certain, that, hitherto, they had not been found, in spite of all attempts.

3. *Theories of the transmission of light.*

In place of explanations there have been the theories of Huygens and Newton, two hundred years ago, put forward as explaining, in some measure, the transmission of light; and again, the modification of Huygens' theory, by Dr Young, a hundred years ago, which latter up to the present time has carried all before it.

Thus for the last hundred years the idea of the structure of the universe, or the luminiferous ether, which has prevailed, is that of space occupied by an incompressible elastic jelly yielding to tangential stress, having a density which is all but indefinitely small.

And so the idea which has alone prevailed

as to the structure of the universe is such as approximates to empty space.

There have been other ideas not so much as to the structure of the universe, which have been strongly held; these will however come in at a later stage, while our attention is turned to the ideas, as to the structure, which follow as the results of an exhaustive research "On the sub-mechanics of the universe."

4. *The granular structure of the universe.*

This research has occupied 20 years, and is just now completed.

It has revealed the *prime cause* of the physical properties of matter.

And, notwithstanding the time it has taken to find them, the results are for the most part of marvellous simplicity; although, on the other hand, so contrary to previous conceptions as to entail an inversion of ideas hitherto advanced.

Before, however, we proceed to sketch the results of the research it seems necessary to give some account as to the manner in which these results have been obtained.

Certain steps, as it now appears, were taken for objects quite apart from any idea that they would be steps towards the mechanical solution

of the problem of the universe. The first of these steps was taken in 1874 with the object of finding a mechanical explanation of the sudden change in the rate of flow of the gas in the tubes of a boiler when the velocity reached a certain limit; perhaps this would be better described as a step towards a step*.

The second step was the discovery of the thermal transpiration of gas, together with the analytical proof of the dimensional properties of matter†.

The third step was the discovery of the criterion of the two manners of motion of fluids ‡. And it was only on taking the fourth step, namely, the study of the action of sand, which revealed dilatancy as the ruling property of all granular media§ which directed attention to the possibility of a mechanical explanation of gravitation. In spite of the apparent possibility all attempts to effect the necessary analysis failed at the time.

There was, however, a fifth step; the effecting of the analysis for viscous fluids, and the determination of the criterion‖, which led to the

* 'Manchester Lit. and Phil. Soc.,' 1874–5, p. 7.

† 'Phil. Trans.,' 1879.

‡ 'Phil. Trans.,' 1883.

§ 'Phil. Mag.,' 1885.

‖ 'Phil. Trans.,' 1895.

recognition of the possibility of the analytical separation of the general motion of a fluid into mean varying motion, displacing momentum, and relative motion, without mean momentum ; and this suggested the possibility that the medium of space might be granular, the grains being in relative motion, and at the same time being subject to varying mean motion. And this has proved to be the case.

At the same time it became evident that it was not to be attacked by any method short of the general equations of a conservative system starting from the very first principles ; and it is from such study that this purely mechanical account of the physical evidence has been obtained.

Apart from the introduction the analysis is effected in sections II to XV.

II. The general equations of motion of any entity—axiomatic.

III. The general equations of motion in a purely mechanical medium, *i.e.* a medium in which the energy is purely kinetic, which can only be,

1. empty space.
2. perfect fluid.
3. perfect solid.

IV. The equations of continuity for component systems of motion.

V. The mean and relative motions of a medium.

VI. The approximate equations of component systems of mean and relative motion.

VII. The general condition for the continuance of component systems of mean and relative motion.

VIII. The conducting properties of the absolutely rigid granule-ultimate atom or primordium.

IX. The probable ultimate distribution of the members of granular media, as the result of encounters, when there is no mean motion.

X. Extensions of the kinetic theory to include rates of conduction of momentum and energy through the grains, when the medium is in ultimate condition and under no mean strains.

XI. The redistribution of angular inequalities in the relative system.

XII. The linear dispersion of mass, and of momentum and energy of relative motion by convection.

XIII. The exchanges between the mean and relative systems.

XIV. The conservation of inequalities in the mean mass and their motions about local centres.

XV. The determination (1) of the relative quantities α'', λ'', σ, and G which define the state of the medium by the results of experience; (2) the general integration of the equation.

From the research it appears that the motion of the medium must be such as admits of analytical separation into two systems:

(1) A system of mean varying motion, displacing momentum:

(2) A system of relative motion without mean momentum, within a certain space.

It also appears:

(3) that it is only media consisting of absolutely rigid parts that can satisfy the condition of being mean and relative systems of motion.

(4) that the rigid parts must be uniform spheres.

The actions between such spheres is outside all experience. But it follows, since there is no elasticity, that for the conservation of energy, when these spheres, or grains, as they will now be called, come into collision, they will exchange

their momenta, on the instant, and thus displace momentum and energy by instantaneous conduction.

This displacement by instantaneous conduction may be illustrated on billiard-tables; for when one ball strikes another at rest, if in the same line, the first stops while the other takes up its motion a full diameter in front, whence the instantaneous displacement of momentum and energy.

The arrangement, or piling, of the grains, is

FIG. 1.

normal when the mean position of each of the grains is such that every grain is at the same mean distance from each of its twelve neighbours; as shown in models 1 and 2. Model 1 shows the normal piling, model 2 shows the twelve neighbours of the grain in normal piling.

FIG. 2.

Then, if the grains are in relative motion, under pressure, from the outside, such relative motion would entail the separation of the mean positions of the grains, according to the outside pressure and the relative velocity of the grains—the piling remaining normal.

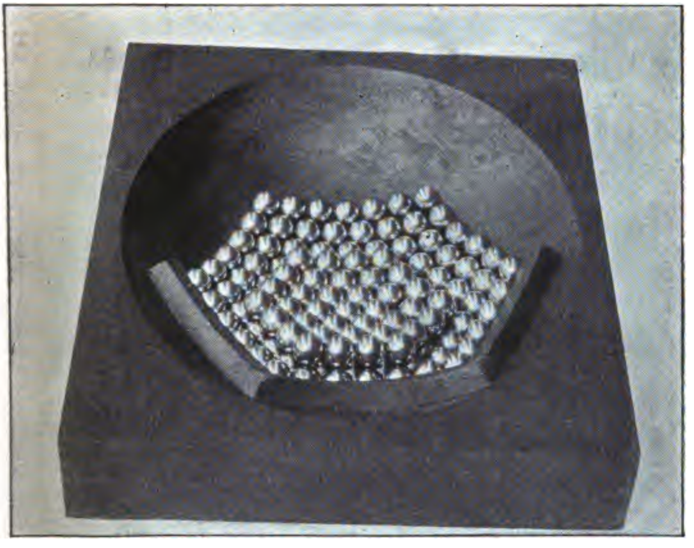

FIG. 3.

The curvature as shown in model 3, in which the grains are in a bowl in two layers, the bowl being somewhat tilted, is very evident in the lines of grains in the lower layer which extend beyond the grains in the upper layer. And the conformation of the lines of grains in the upper layer may be traced.

Strained normal piling implies that, although the shape of the medium is strained, so that the distances of the grains from their twelve neighbours are no longer equal—since the successive layers of grain in the normal piling instead of being flat are subject to slight spherical curvature—the strains are such as do not allow any change of neighbours; so that when the strain is removed each grain will find itself in normal piling with the same neighbours.

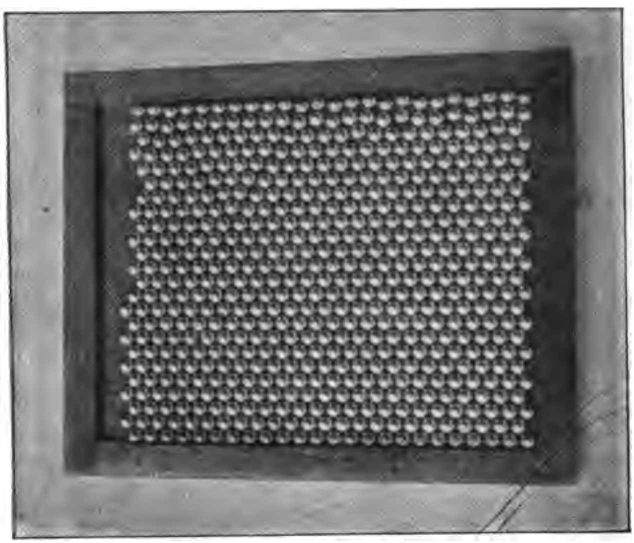

FIG. 4.

Abnormal piling implies any disarrangement which displaces the grains in the medium from their neighbours and so affects the gearing of the grains, as shown in models 4 and 5; in 4 the piling is approximately normal, the edges being free, while in 5 the piling is so abnormal as to prevent, entirely, the gearing in several lines.

The relative motion of the grains renders the medium elastic: and is thus the only cause of

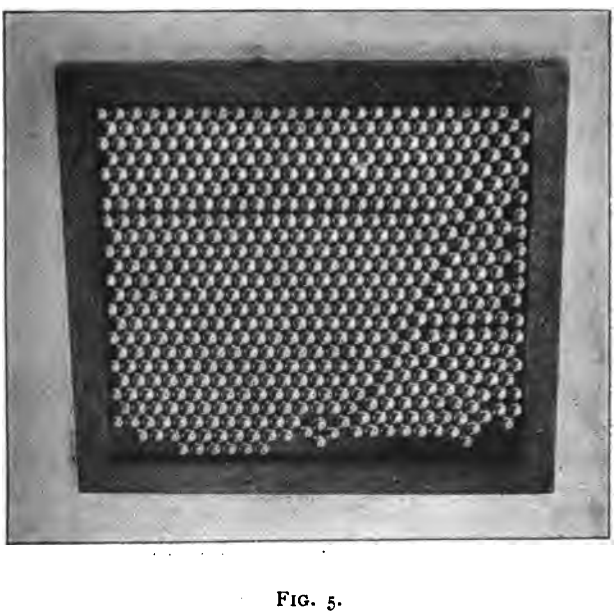

FIG. 5.

elasticity in the universe, and, hence, is the prime cause of the elasticity of matter.

The grains which are of definite size are inconceivably small; their diameters being—as measured by the wave-length of violet light—only the *seven hundred thousand millionth part of the wave-length.*

While the mean path of the grains, as compared with the diameter of the grain, is only the *four hundred thousand millionth part of the diameter of the grain.*

The mean relative velocity of the grains is about *one and one-third feet per second.*

These three quantities define the state of the medium in spaces where the piling is normal; and also define the mean density of the medium as being *ten thousand times greater than that of water, or, as being four hundred and eighty times* greater than that of the densest matter on the earth.

The mean pressure of the medium is nearly *seven hundred and fifty thousand tons on the* square inch, being more than *three thousand* times greater than the strongest material can sustain.

The coefficient of the transverse elasticity, resulting from the pressure and gearing of the

grains, in C.G.S. units is ***nine multiplied by ten to the power of twenty-four;*** and from this it follows that the rate of the transverse wave is that of light; while that of the normal wave is *two and four-tenths greater* than that of the transverse wave.

Then as the general result of the research, in spaces in which the piling is normal, which spaces are almost indefinitely greater than those occupied by matter, it is shown, that there is one and only one conceivable purely mechanical system capable of accounting for all the physical evidence, as we know it, in the universe.

The system being neither more nor less than an arrangement of indefinite extents of spherical grains in normal piling, so close that the grains cannot change their neighbours, although continually in relative motion with one another; the grains being of changeless shape and size. Thus constituting, to a first approximation, an elastic medium, with six axes symmetrically placed, see Fig. 2, p. 10. This, then, is the structure of the universe, except in the comparatively indefinitely small spaces in which there is matter;—grains in normal piling, of which the size, mean path, relative velocity and mean pressure are defined, and extend to infinity. Could anything be more simple?

In place of an elastic medium, of density approximating to empty space, we have this definite granular structure of the universe, elastic and of density ten thousand times that of water.

5. *The degradation of light.*

Up to the present time it has been a moot question whether there is any loss of light in transmission. Herschel held that there was none. But it is now shown that, owing to the angular *redistribution* or viscosity of the grains, there is degradation, such as would require fifty-six millions of years to reduce the total initial energy of the light to one-eighth, while the rate of the degradation of the normal wave, owing to the linear redistribution of the grains, is such as would be reduced, in the same ratio, in the two hundred and fifty thousandth part of a second; thus accounting for the absence of any evidence of normal waves except such evidence as might be obtained within some thousands of metres from its origin; as in the case of *Röntgen rays*.

And we thus have an explanation of the blackness of the sky on a clear dark night as a consequence of the dissipation of the mean motion of light to increase the relative motion of the grains.

6. *The permanence of the inequalities.*

In spaces in which there are inequalities, owing to the presence or absence of a number of grains, in deficiency or excess of the number which would render the piling normal about local centres in the medium, these are permanent, as is now shown. And these are attended by inward or outward displacements and strains in the normal piling, as the case may be, extending indefinitely through the medium, causing everywhere dilatation equal to the strain but of opposite sign.

And, according to the evidence, the diameters of such inequalities are about 100-1000th of the wave-length.

When the arrangement of the grains about the centres is that of a nucleus of grains in normal piling on which the grains in strained normal piling rest, the nucleus, in normal piling, cannot gear with the grains in strained normal piling; so that there is a singular surface of misfit between the nucleus and the grains in strained normal piling.

Such singular surfaces are surfaces of weakness, and may be surfaces of freedom or surfaces of limited stability with the neighbouring grains.

7. *Mobility of the medium.*

The singular surfaces, when their limited stability is overcome, are free to maintain their motions through the medium by a process of propagation in any direction—the number of grains forming up on the grains already in position being the same as those left behind; so that the grains in the nucleus have no mean motion whatever.

Any conception of this external propagation is difficult. But the process admits of such

FIG. 6.

experimental demonstration as explains the apparent paradox presented by a nucleus within the surface of which the grains are at rest, in the normal piling, propagating through the medium in one direction, while the only mean motion, that of the grains in strained normal piling, outside the nucleus, are moving in the opposite direction.

The apparatus is shown in Figs. 6 and 7.

In this apparatus, Fig. 6, the six balls in close order in the lower chase constitute the

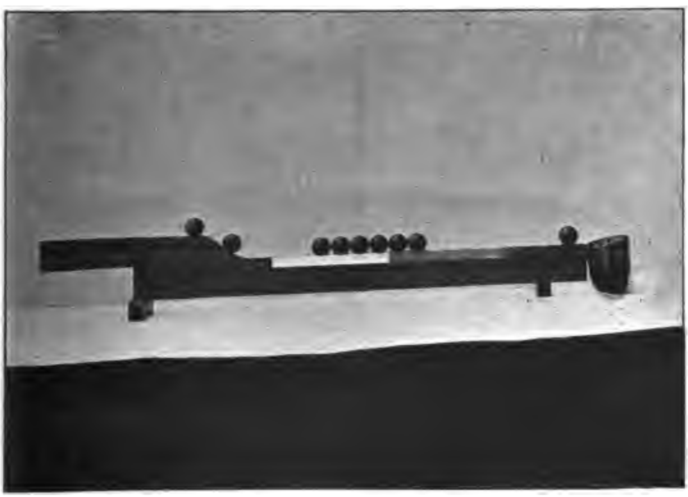

FIG. 7.

nucleus, and the other balls, higher up, represent the medium, which is strictly limited. The gap between these two sets of balls represents the inequality which is to propagate through the medium for a distance of 18″, as soon as the inequality receives an impulse by the removal of the block on the upper chase, when the ball runs down, and, as you see, the nucleus has advanced 18″.

The progress of the action is shown in Fig. 7. The downward slope in the upper chase being uniform for a small distance beyond the position of the stop; then varying, as an inverted S, so as to be horizontal at the level of the lower chase—when the stop is removed the balls start with nearly equal acceleration, then having accelerated, when they reach the steep slope they are separated. And thus the first ball from the upper chase reaches the first ball in the lower chase somewhat ahead of the second ball from the upper chase, and strikes the first ball in the lower chase when it comes to rest without disturbing any of the balls which were in the lower chase except the last, which takes up the motion and runs on towards the basket: the momentum having been conducted through the six balls. Thus the nucleus has advanced in

the opposite direction to that of the motion ot the grains, or balls, in strained normal piling by the diameter of a ball.

And in the same way for each of the remaining five balls, each grain as it comes down causes the nucleus to advance by a diameter in the opposite direction to that ball. Fig. 7 shows the action in progress when there have been four encounters. Three balls have disappeared into the basket, and one is on its way to the basket; the nucleus has advanced four diameters. One ball is still on the upper chase, while another is on the steep slope.

Then, when the inequalities are such as result from an absence of grains, the singular surfaces correspond to the molecules of matter.

It may help in the formation of a conception if we recal Lord Kelvin's theory of vortex atoms which promised so much, and afforded the first conception of matter passing through a space completely occupied by matter without resistance. In that theory the vortex ring, in which the displacement is from the inside, was the instrument, so to speak, that was to secure the free motion of matter through the medium. This theory has been found intractable, and is now shown to be impossible. But in its place we

have the external propagation, which presents none of the difficulties of its predecessor.

Nor can we pass this stage without calling attention to the startling conclusion to which this external propagation leads.

8. *Singular surfaces are wave surfaces.*

It is shown that the matter of the molecules passes freely through the medium or *vice versâ*. What does this imply?

That the singular surface has all the characteristics of a wave boundary.

If the medium is stationary and the molecules are moving with the earth, the grains within the surfaces do not partake of the mean motion of these surfaces, being continuously replaced by other grains by the action of propagation, by which the singular surfaces in their motion are continually absorbing the grains in front and leaving those behind without any mean effect on the motion of the grains. And thus there is perfect freedom of motion of the molecules or aggregate matter, although the grains which constitute the nuclei are changing at the rates expressed by 20 miles a second.

To be standing on a floor that is running away at a rate of 20 miles a second without

being conscious of any motion, is our continual experience; but to realize that such is the case is, certainly, a tax on the imagination.

Such motion has all the character of a wave in the medium; and that is what the singular surfaces, which we call matter, are—waves. We are all waves.

9. *The molecules are individuals.*

The singular surfaces which we call molecules are individuals, which, although they may cohere, cannot pass through each other; and thus although the only mass, that of the medium, is changing every instant, at the extreme rates already mentioned, these singular surfaces or molecules preserve their individuality, the realization of which is a further tax on the imagination.

10. *Negative inequalities.*

When the singular surface of a negative inequality is propagating through the medium, which is at rest, the grains forming the nucleus will have no mean motion, whatever may be the motion of the surface. But the strained normal piling which surrounds the surface, and propagates with the surface, being of less density than the mean density of the medium, represents

a displacement of the negative mass of the inequality, *i.e.*, of the grains absent, and in whatever new direction the surface is propagating, the motion of the medium, outside the surface, is such as represents equal and opposite momentum, as when a bubble rises in water.

And in the same way for the inequality resulting from an excess of grains, the momentum would be positive.

11. *The principal stresses in the medium.*

The principal stresses outside the singular surface of a negative inequality are to a first approximation,

Two equal tangential pressures equal to $\frac{6}{5}$ of the mean pressure in the medium, and a normal pressure equal to $\frac{3}{5}$ of the mean pressure in the medium. The resultant of the pressures being everywhere equal to the mean pressure of the medium.

12. *The cause of gravitation.*

We have now sketched the structure of the inequalities, where inequalities exist, as resulting from the presence or absence of grains, the permanence of the singular surfaces, and their freedom of motion by propagation, and have

thus arrived at what may be called the historical problem, as to the cause of gravitation.

From Kepler's discoveries of the relation between the distances and periodic times of the planets, Newton was able to show that the law of gravitation is as the inverse square of the distance. But this in no way explained the cause of this law. And in spite of all attempts in the mean time, up to the year 1885 no clue had been found.

In that year, however, as the result of an attempt to discover what properties a medium possesses, that it might fulfil the functions of the ether, including gravitation, the property of all granular matter in close piling to expand under strain was recognized, I believe for the first time.

This property was at once recognized as an obvious clue to the cause of gravitation, however intractable it might prove.

The experiments made in 1885 will serve to illustrate the cause of gravitation, besides affording me the gratification, I cannot but feel, in first exposing the verification of my conviction in this house and before this audience.

Hitherto in this lecture it has been found necessary to refer to granular medium as con-

tinuous in space. But it is doubtful whether the significance of this continuity has been realized.

We have defined the pressure in such media as being enormous, and it now becomes necessary to realize that, in order to get granular material under pressure, one or other of two conditions must be satisfied.

If, as in the universe, the grains in normal piling extend indefinitely there cán be no mean motion of the boundaries, whatever the pressure may be; and thus the grains are virtually within a closed surface.

But if the number of grains is limited—and we can only experiment on a finite number of grains—it is necessary, in order to realize the dilatation, that the grains should be in a closed envelope of some kind which constrains them; and it may be mentioned here that the reason why dilatancy had not been discovered previously was undoubtedly the general absence of any constraining surface.

Without such a surface, in order to illustrate the dilatation, we may join the horizontal layers of grains in normal piling together, as in model (1), then subjecting these layers of grains in normal piling to transverse strain, the dilata-

tion which results from parallel distortional strain in the normal piling becomes evident, as

FIG. 8.

is shown by comparing model 1, p. 9, in which the grains are in closest order, with model 8, in which the grains are shown in maximum dilatation.

But this only affords a very partial illustration of the possibilities of the general dilatation,

when all the grains are separate, and only constrained by the pressure outside the constraining surface.

I have in my hand the first experimental model universe, a soft indiarubber bag with a small aperture to admit of its being filled with small shot; which aperture is partly closed, sufficiently to prevent the shot from coming out, by a glass tube which also serves the purpose of a gauge to measure the dilatation. After filling the bag with small shot, the interstices are filled with highly coloured water, and subjecting the bag to small distortional strains to get the shot in normal piling: then in order to render apparent the inverse behaviour of bag with shot and water under distortional strains we take another similar bag with a similar tube filled only with water and subject both to similar distortional squeezing. When, as was obvious, the water in the tube of the bag without shot rises in the tube; while on the contrary the water in the tube with shot sinks, drawing water from the tube into the bag, as is shown respectively in figs. 9 and 10, and 11 and 12.

It is thus shown that any deformation from the normal piling causes the interstices between the grains to increase, expanding the bag. This

FIG. 10.

FIG. 9.

FIG. 12.

FIG. 11.

experiment, which you see is on a very small scale, was not designed to show to an audience, being the original experiment made for my own satisfaction when the idea of dilatancy first presented itself.

Without knowledge of dilatancy the results thus obtained must appear paradoxical, not to say magical.

Taking a larger apparatus, a bag which holds six pints of sand, the interstices being filled with water, without any air, the glass neck being graduated, so as to measure the water drawn in and the sand and water subjected to such distortion as would cause the grains to be in normal piling.

Then, if the neck be closed so that it cannot draw more water, we come upon the startling fact, that this indiarubber bag, filled with sand and water, cannot have its shape changed without a sufficient distorting pinch, as by these pincers, to cause a vacuum inside the bag.

The pinch is now some 200 lbs., but the bag does not flinch. It cannot change its shape without drawing water into the bag and this is prevented.

To show that there is an effort to expand the bag, while the pinch is on, it is only necessary

to bring the bag into communication with a pressure-gauge, when the mercury shows that the pressure in the bag is only half of that of the atmosphere outside the bag.

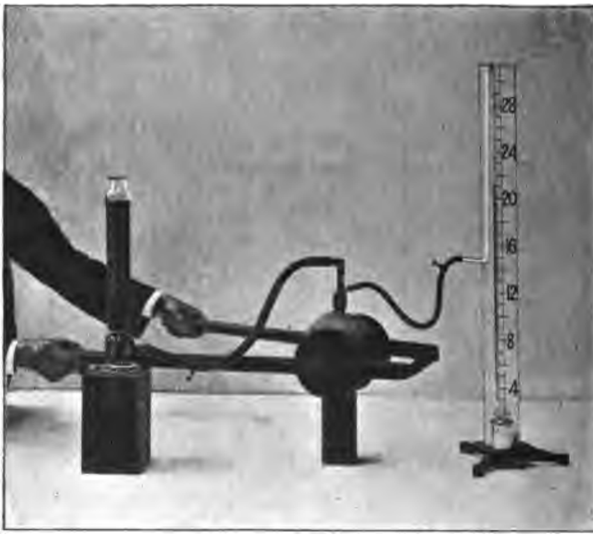

FIG. 13.

Had the pinch been greater a vacuum would have been caused within the bag by the expansion of the interstices. As it is, however, the bag has maintained its rigidity.

Then, if the pressure-gauge is closed and the neck opened, so that water may be drawn in, the

bag at once begins to change its shape, the water sinks in the neck until a pint of water has been drawn into the bag.

FIG. 14.

This is the maximum dilatation, the grains are now in the most open order into which they can be brought by squeezing. Further squeezing causes the grains to take closer order, so that the interstices diminish and the water rises in the neck.

The dilatation of sand is well shown by india-rubber balloons, which can be expanded by the mouth, these afford an almost transparent

FIG. 15.

envelope. Taking one which holds six pints of sand and water, closed without air, there being more water than will fill the interstices at maximum density, but not enough to allow the full extension of the interstices. When standing on a table the elasticity of the envelope gives it a

rounded shape; the sand has now settled down to the bottom, and the excess of water appears above the sand, the surface of which is free. The bag may now be squeezed and its shape altered, apparently without resistance; but this is only as long as the surface is free.

FIG. 16.

Putting the bag between two vertical plates and slightly shaking and squeezing, so as to keep the sand at its densest, it still has a free surface and it can, in this way, be spread out until

it is a broad flat plate; it is still soft, as long as it is squeezed, but when the pressure is removed the elasticity of the bag tends to draw it back to its rounded form, changing the shape, enlarging the interstices and absorbing the excess of water. This is soon gone and the bag remains a flat cake with peculiar properties; to pressures on its

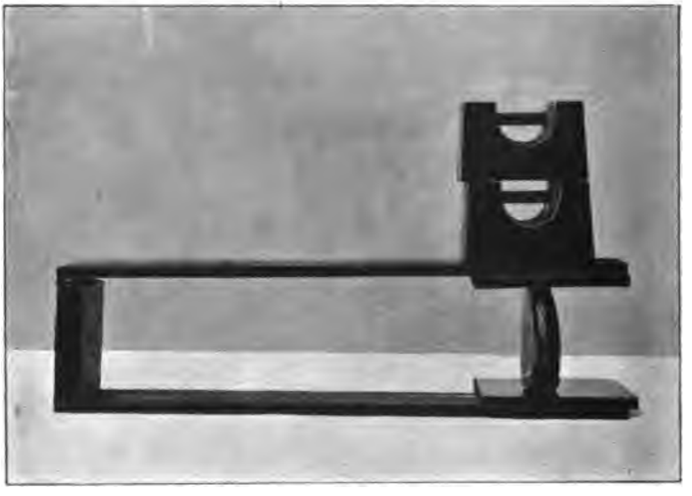

FIG. 17.

sides it yields at once, such pressures having nothing to overcome but the elasticity of the bag since change of shape in that direction diminishes the interstices. But to pressures on

its edge it is perfectly rigid, as such pressures tend to increase the interstices; when placed on its edge it sustains 2 cwt.

These experiments made on tangible matter fall short of what would be the dilatations if made with absolutely rigid uniform spheres. But after seeing the evidence that dilatation is the ruling property of granular matter, I venture to think that you will agree with me that without this clue the cause of gravitation would not have been discovered.

It now appears, however, as a complement to dilatation, in causing gravitation, we have the relative motion of the grains, which has already been shown to impart the elasticity necessary for the transmission of light, and this affords the complement for the complete explanation.

But, even so, the explanation is not what was expected; for gravitation is not the result of that dilatation which results from uniform parallel strains in the medium in normal piling, but results solely from those components of the dilatations caused by the space variation of the inward strains.

Thus, as long as the dilatation strains are parallel there is no attraction; but if there is curvature in the strains there will be efforts,

proportional to the inverse square of the distance, to cause the negative inequalities to approach from a finite distance.

Thus gravitation is the result of those components of the dilatations (taken to a first approximation) which are caused by the variations of the components of the inward strains, caused by curvature in the normal piling of the medium.

The other components of the strains, being parallel distortions, which satisfy the conditions of geometrical similarity, do not affect the efforts.

Then, since if the grains were indefinitely small, while the curvature in the normal piling was finite, there would be no effort. And thus the diameter of the grains becomes the parameter of the effort. And multiplying this parameter by the curvature of the medium, and again by the mean pressure of the medium, the product measures the intensity of the efforts to approach.

The dilatation diminishes as the centres of the negative inequalities approach, and work is done by the pressure, outside the singular surfaces, to bring the singular surfaces of the negative inequalities together.

The efforts to cause the approach of the centres correspond, exactly, to the gravitation

of matter if matter represents the absence of mass, and thus the inversion of preconceived ideas is complete. Matter is measured by the absence of the mass necessary to complete the normal piling. And the effort to bring the negative inequalities together is also an effort on the mass to recede; and since the actions are those of positive pressure, there is no attraction involved, the efforts being the result of the virtual diminution of the pressures inwards, and in this inversion we have a complete, quantitative, purely mechanical explanation of the cause of gravitation.

13. *Positive inequalities.*

The explanations of the transmission of light and the cause of gravitation do not complete the explanation necessary to satisfy all the evidence.

Thus far we have sketched the efforts of negative inequalities only.

The efforts of the positive inequalities are the reverse of the negative inequalities, tending to separate the positive centres, and cause the positive inequality to scatter through the medium, thus dissipating any effects throughout the medium. Then, since the space occupied by inequalities is almost indefinitely small com-

pared to the space in normal piling, it appears, even if there are as many positive inequalities as there are negative inequalities, the positive will present no evidence, being scattered, while the negative inequalities being brought together by gravitation, are in evidence.

Besides the positive and negative inequalities, there is another inequality which can easily be conceived.

Whatever may be the cause it is possible to conceive that a number of grains may be removed from one position, in the medium, to another position, the medium being otherwise uniform; thus instituting a complex inequality, as between two inequalities, one positive and the other negative, the number of grains in excess in the one being exactly the same as the number absent in the other.

Such complex inequalities differ fundamentally from the gravitating inequalities, inasmuch as the former involve the absolute displacement of mass, while the latter have no effect on the position of the mean mass in the medium: and in respect of involving absolute displacement of mass, the complex inequality corresponds with electricity.

Apart from the displacement of mass, the

complex inequality differs from the gravitating inequalities.

In the complex inequalities the parameter of the dilatation is not the diameter of the grain, but is one half the linear dimension of the volume of the grain displaced taken as spherical.

The intensity of the efforts to revert in the case of a complex inequality is the product of the pressure multiplied by the product of the volumes of the positive and negative inequalities, and again by the parameter.

Thus we have a purely mechanical explanation of electricity. And not only so, for we have also a determination of what has been a moot question—is electricity one thing or two?

For since the absolute displacement of mass is one displacement, and the expression for the inequality is negative, it is such as cannot be resolved, as hitherto assumed, into two rational factors.

It is interesting to compare the efforts of gravitation with the efforts to revert of electricity.

If we consider the case of two gravitating inequalities, at unit distance, and compare with these a complex inequality, the number of grains and distances being the same, it is found

that the effort to revert of the complex inequalities, is more than one thousand billion times greater than that of the gravitating inequalities.

The cohesions and surface tensions, on which the strength of our structures depend, are the result of the manner in which the efforts to approach vary, when within distances which are small, as compared to the dimensions of the molecules, and are thus the complements of gravitation.

14. *The cause of light.*

Although we have already sketched the transmission of light it is only now that we come to the cause of light.

The institution of the waves of light follows as the result of the disruptive reversion of the complex inequalities, or electric-discharges; the recoil from which sets up a vibration, in the medium, which is exhausted in initiating waves of light and heat.

Thus far the sketch of the new ideas has included only those for which there exists sufficient evidence to admit of definite quantitative analysis.

Nevertheless these quantitative results show

that the granular medium, as already defined, accounts by purely mechanical considerations for the evidence; and also affords the only purely mechanical explanations possible.

If then the substructure of the universe is mechanical, all the evidence, not already adduced, is such, as may be accounted for, by an extension of the analysis; and, thus far, this has been found to be the case.

Thus we have the purely mechanical explanation of the absorption of light by the molecules of matter;

The dispersion of the spectrum;

The association and dissociation of the molecules;

The refraction of light;

The polarization of light by reflection, and as it now appears this is caused only by that component of the motion of the transverse wave which is in the plane of incidence; also

The metallic reflection of light;

And of the aberration of light, as resulting from the absence of any appreciable resistance to the passage of matter through the medium.

Then, considering that not one of these phenomena had previously received a mechanical explanation, it appears how indefinitely small

must be the probability that there should be another structure for the universe which would satisfy the same evidence.

And thus we may have the fullest confidence that the structure is purely mechanical, and that ideas, such as I have endeavoured to sketch, will ultimately prevail, displacing for ever such metaphysical conceptions as that of action at a distance, and accomplishing that ideal which, from the time of Thales and Plato, has excited the highest philosophical interest.

CAMBRIDGE: PRINTED BY J. AND C. F. CLAY, AT THE UNIVERSITY PRESS.